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B—5—2 Minority Carrier Diffusion Lengths in Silicon Ribbon Solar Cells

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Silicon ribbon crystal is expected to be one of the most hopeful materials to realize low-cost solar cells. Most silicon ribbon crystals have, however, various types of crystal defects, where electrically poor characteristics are often observed.[1][2] It is an effective means to measure the minority carrier diffusion length in order to study the influence of crystal defects on solar cell performances. In this paper, experimental results of the dependences of minority carrier diffusion length on crystal defects and also on majority carrier density, will be described. The results indicate that high quality silicon ribbon solar cells can be obtained using higher carrier density base materials.

The specimens used in the experiments were fabricated from As-doped n-type silicon ribbon crystals, which were grown by pulling vertically from a thin sheet of molten silicon in a gap between a pair of carbon dice.[1]

The diffusion lengths were measured using a scanning electron microscope. Electron beam was focused on the cleaved surface of the p-n type solar cell. Electron beam induced current (EBIC), I_e, was measured as a function of distance x between impinging beam and p-n junction, and effective diffusion length L_{eff} was calculated using the equation $I_e \propto \exp(-x/L_{eff})$. Bulk hole diffusion length L_p was estimated according to the equation[3]

$$L_{eff}^2 = L_p^2[1-\exp(-\xi/L_p)]$$

where ξ is electron beam penetration depth, which depends on the accelerating voltage V of the electron beam. This equation was deduced by assuming that surface recombination velocity was infinite in the case of silicon ribbon crystals. Figure 1 shows the measured I_e-x characteristics of the ribbon crystal of $n=3.0\times 10^{16}\ cm^{-3}$. L_p was estimated at 11.1, 10.8 and 11.3 μm, corresponding to V=20, 25 and 30 kV, respectively. Estimated L_p values are in good agreement with each other, which verifies the above-mentioned assumption.

Figure 2 shows secondary electron (SE) and EBIC images of the silicon ribbon solar cell cleaved surface. Irregular boundary[1] was observed at the region where the white band of the EBIC image is narrowed in the figure. Diffusion lengths were measured at regions with and without the irregular boundary. Results are shown in Fig.3. At irregular boundary, hole diffusion length L_p is reduced by a factor of more than 2, which shows that irregular boundaries degrade solar cell performances.

The dependence of L_p on carrier density was investigated for the specimens which contained no appreciable crystal defects. Figure 4 shows the results obtained for the ribbon crystals in the range of $1.7x10^{16} \sim 1.0x10^{17}$ cm^{-3}. As is seen in the figure, L_p has no appreciable dependence on electron density. Hole diffusion length in ribbon crystals is considered to be affected more by bulk crystal characteristics such as dislocation density. This result indicates that photocurrent is almost independent of electron density, therefore ribbon crystals with higher electron density are preferable to obtain higher quality solar cells. The solar cell of the dimension 2x10 cm with the efficiency of 11.1 % at AM2 condition, was realized using n-type silicon ribbon crystal of $n=1.0x10^{17}$ cm^{-3}.

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(2) K. V. Ravi et al, 11th IEEE Photovoltaic Specialists Conf., 280(1975).
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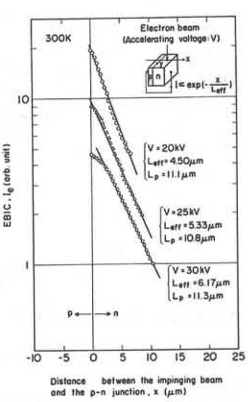

Fig.1

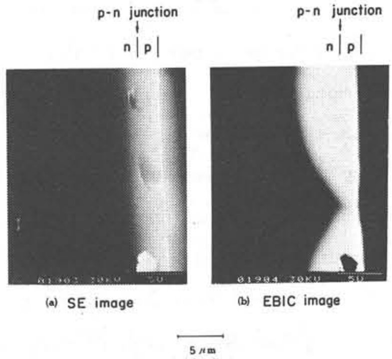

Fig.2

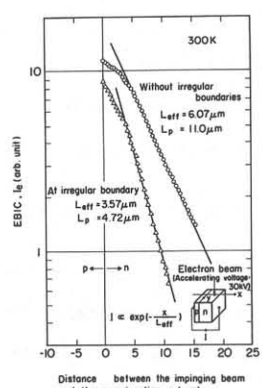

Fig.3

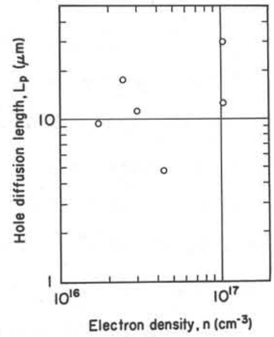

Fig.4